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I, JULIE BILLINGSLEY, TEAM LEADER EXAMINATION SUPPORT AND SALES hereby certify that annexed is a true copy of the Provisional specification in connection with Application No. 2003904207 for a patent by VAST AUDIO PTY LTD as filed on 11 August 2003.

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Patents Act 1990

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PROVISIONAL SPECIFICATION

Invention Title:

Enhancement of sound externalization and separation for hearing-impaired listeners: a spatial hearing-aid

The invention is described in the following statement:

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Enhancement of sound externalisation and separation for hearing-impaired listeners: a spatial hearing-aid

Field of the Invention

This invention relates to providing spatial hearing for listeners wearing hearing-aids. More particularly, the invention relates to a method of, and equipment for, processing hearing-aid sound signals so that sound externalisation and sound separation is improved.

Background to the Invention

Listeners wearing all prior art hearing-aids demonstrate a substantial reduction in their sound externalisation and sound spatialisation and this in turn significantly reduces their ability to parse sounds of interest from competing background sounds. Normally-hearing listeners, on the other hand, rely on their spatial hearing to separate competing sounds based on their different spatial locations. Sound spatialisation also assists normally-hearing listeners to focus attention on sounds of interest.

Human spatial hearing relies on the integration of acoustic information from the two ears. This acoustic information consists of the binaural difference in the intensity and time of arrival of sound between the two ears and also the monaural spectral cues that result from the location-dependent acoustic filtering of sounds by the outer ear (see *Virtual auditory space: Generation and applications*, S. Carlile, Landes: Austin, 1996). The perception of externalised sounds (i.e., sounds that are heard as outside of the head) relies primarily on the monaural spectral cues provided by the acoustic filtering of the outer ear. Sounds without these spectral cues, but with a consistent interaural time difference cue and interaural intensity difference cue, are perceived as lateralised and inside of the head. Because hearing-impaired listeners usually suffer greater hearing loss at the higher frequencies, the most difficult problem with spatialisation for these listeners when using hearing-aids is the fact that the frequency range over which the monaural spectral cues operate is generally from 5 kHz to 16 kHz (a result of the shape and size of the outer ear, see *Human sound localisation of bandpass filtered noise*, A. van Schaik *et al.*, Intl. J. of Neural Systems, p. 441-446, 1999). Furthermore, it is the very high frequencies greater than 8 kHz that are required for accurate spatialisation of speech stimuli (see *Speech Localisation*, C. Jin *et al.*, Proc. of the 112th Conv. of the Audio Eng. Soc., May, 2002).

The prior art discloses various means for enhancing the spatial hearing of listeners wearing hearing-aids.

Some of the prior art methods for enhancing the spatial hearing of listeners wearing hearing-aids use miniature, completely-in-the-canal (CIC) hearing-aids to avoid interference with the acoustic filtering of the outer ear. The electronics for the CIC hearing-aids are contained within a small mould that is completely contained within the auditory canal.

Some of the prior art methods for enhancing the spatial hearing of listeners wearing hearing-aids use open or non-occluding ear moulds that do not distort the low-frequency interaural time difference cues (see *National Acoustic Laboratories Annual Report 1996-7*, D. Byrne *et al.*).

Some of the prior art methods for enhancing the spatial hearing of listeners wearing hearing-aids adjust the gains of the left and right hearing-aids based on empirical localisation tests to best preserve the interaural intensity difference cues (see US Patent 5870481).

A disadvantage of all of the prior art methods for enhancing the spatial hearing of listeners wearing hearing-aids is that they do not use signal processing to enhance and provide high-frequency monaural spectral cues that vary consistently with the location of the sound in space.

A disadvantage of all of the prior art methods for enhancing the spatial hearing of listeners wearing hearing-aids is that they do not make the very high frequency spectral cues (> 8kHz) more audible.

Terms related to this invention are defined here.

The term "speech frequency band" is the frequency range (approximately and not exactly 200 Hz to 4 kHz) that is empirically most important for a listener's speech perception. It may vary slightly from listener to listener and may be determined empirically and/or analytically.

The term "high frequency sound component" refers to a frequency component that occurs above the speech frequency band.

The term "high-frequency band" refers to the frequency band above the speech frequency band.

<u>Summary of the Invention</u>

According to a first aspect of the invention, there is provided a method for enhancing the spatial hearing of listeners wearing a hearing-aid in either one ear or both ears, the method including the steps of applying signal processing within the hearing-aid either before or after the customary compression and amplification signal processing of the hearing-aid, such that the high-frequency components (above the speech frequency band) of a sound are compressed across frequency and/or shifted to lower frequencies, with or without loss of frequency information and with or without signal amplification, in such a manner that the speech frequency band is not disrupted or remains mostly undisrupted, and such that monaural spectral cues are available to the listener for sound externalisation and spatialisation.

According to a second aspect of the invention, there is provided a method for enhancing the spatial hearing of listeners wearing hearing-aids, the method including the steps of aspect one where the hearing-aid is a completely-in-the-canal (CIC) hearing-aid that preserves the normal acoustic filtering of the outer ear.

According to a third aspect of the invention, there is provided a method for enhancing the spatial hearing of listeners wearing hearing-aids, the method including the steps of the first aspect and optionally the second aspect, where the high-frequency hearing range suitable for the listener's spatial hearing is individually and empirically determined for the listener and the compression across frequency and/or shift to lower frequencies is customised to the listener's high-frequency hearing range.

According to a fourth aspect of the invention, there is provided a method for enhancing the spatial hearing of listeners wearing hearing-aids, the method including the steps of aspect one and possibly any of the steps of aspects two to three, where the high-frequency components of a sound are compressed across frequency and/or shifted to lower frequencies, by first transforming the sound signal to the frequency domain using methods common in the art, such as using a Fourier-transform or a sub-band decomposition via filter bank processing, and then modifying the sound's frequency domain representation by replacing the frequency components from f_1 to f_2 ($f_2 > f_1$) with frequency components from f_3 to f_4 ($f_4 > f_3$, $f_3 \geq f_1$) according to a mapping:

$$S\left(f_1 + (f - f_3)\frac{f_2 - f_1}{f_4 - f_3}\right) \rightarrow S(f), \text{ where } f_3 \leq f \leq f_4.$$

According to a fifth aspect of the invention, there is provided a method for enhancing the spatial hearing of listeners wearing hearing-aids, the method including the steps of aspect one and optionally any of the steps of aspects two to four, where the high-frequency components of a sound are compressed across frequency and/or shifted to lower frequencies using a mapping that preserves, to some extent, the harmonic relationship between the sound's frequency components, such as would occur when using the mapping of aspect four with $f_3 = nf_1$ and $f_4 = nf_2$ (n an integer).

According to a sixth aspect of the invention, there is provided a method for enhancing the spatial hearing of listeners wearing hearing-aids, the method including the steps of aspect one and optionally any of the steps of aspects two to five, where the high-frequency components of a sound are compressed across frequency and/or shifted to lower frequencies using a logarithmic compression such as that described by the ERB frequency scale or the BARK frequency scale as is commonly known within the art.

According to a seventh aspect of the invention, there is provided a method for enhancing the spatial hearing of listeners wearing hearing-aids, the method including the steps of aspect one and optionally any of the steps of aspects two to six, where the high-frequency components of a sound are compressed across frequency and/or shifted to lower frequencies only for those time windows in which

the sound signal contains substantial (as possibly determined by some empirical criterion) high-frequency energy above the speech frequency band.

According to an eighth aspect of the invention, there is provided a method for enhancing the spatial hearing of listeners wearing hearing-aids, the method including the steps of aspect one and optionally any of the steps of aspects two to seven, where the amplification of the high-frequency sound components is applied with consistent, or as consistent as possible, relative gain across frequency for the high-frequency sound components.

According to a ninth aspect of the invention, there is provided a method for enhancing the spatial hearing of listeners wearing a hearing-aid in each ear (binaural hearing-aids), the method including the steps of aspect one and optionally any of the steps of aspects two to eight, where the signal amplification of the high-frequency sound components is applied with consistent, or as consistent as possible, relative gain between the two ears for each frequency band.

According to a tenth aspect of the invention, there is provided an interface to disable the compression and/or shifting to lower frequencies of the high-frequency sound components if or when the listener desires it.

According to an eleventh aspect of the invention, there is provided equipment for enhancing the spatial hearing of listeners wearing hearing-aids, the equipment including:

a supporting means to house the hearing-aid electronics and components,

an acoustic sensing means for recording acoustic signals,

a sound delivery means for playing sounds to the eardrum,

a signal processing means for performing the required hearing-aid signal processing other than that described by this invention,

an energy detecting means and a controlling means to enable or disable frequency compression or frequency shifting,

a signal processing means to electronically compress across frequency and/or shift to lower frequencies the high-frequency sound components of the incoming sound within the hearing-aid.

Brief Description of the Drawing

The invention is now described by way of example with reference to the accompanying drawing in Figure 1 which shows, schematically, equipment, in accordance with the invention, for enhancing the spatial hearing of listeners wearing hearing-aids.

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Detailed Description of the Drawing

In the drawing, reference numeral (1) generally designates equipment, in accordance with the invention, for enhancing the spatial hearing of listeners wearing hearing aids. The equipment includes a supporting means (2) to house the hearing-aid electronics and components, an acoustic sensing means (3) for recording acoustic signals, a sound delivery means (4) for playing sounds to the eardrum, a signal processing means (5) for performing the hearing-aid signal processing other than that described by this invention, an energy detecting means and a controlling means (6) to determine if the high-frequency sound components contain energy above some pre-determined threshold and also control (enable or disable) the operation of the signal processing means (7), a signal processing means (7) to compress across frequency and/or shift to lower frequencies the high-frequency sound components of the incoming sound.

A preferred embodiment is given here as an example. The equipment consisting of components (2) to (5) can be fashioned as a completely-in-the-canal hearing aid, as is customary in the art. In the preferred embodiment there is a broadband (20 Hz to 20 kHz) sound receiver (3) that converts incoming sound waves in the ear canal into an electronic signal. In some embodiments of this invention, the energy detecting means (6) detects, as described in aspect seven, whether the incoming sound signal contains significant energy (above some threshold) in the high-frequency band above the speech frequency band. In the case that there is significant energy in the high-frequency band, the signal processing means (7) compresses across frequency and/or shifts to lower frequencies the high-frequency sound components of the incoming sound signal as described in any of the aspects one to six. In the case that there is not significant energy in the high-frequency band or that the listener has decided to disable the frequency compression via unit (6), the signal processing means (7) passes the incoming sound signal without any modifications to the rest of the hearing-aid's signal processing units (5). In the preferred embodiment, the components (6) and (7) perform a pre-processing function and process the incoming sound signal prior to the customary compression and amplification processing that occurs within hearing aids. In Figure 1, the dashed line is drawn to indicate the separation of the pre-processing function of the signal processing units (6) and (7) from the main signal processing unit (5) of the hearing-aid. In the preferred embodiment, the amplification of the high-frequency sound components by the signal processing unit (5) is performed in such a way that there is always a consistent, or as consistent as possible, relative gain across the frequency components of the high-frequency band, as described in aspect eight. In the preferred embodiment in which a hearing-aid is used in both ears, the amplification of the high-frequency sound components by the signal processing unit (5) is performed in such a way that there is always a consistent, or as consistent as possible, relative gain between the two ears for each frequency component within the high-frequency band, as described in aspect nine.

It is essential for this invention that the hearing-aid preserves some form of monaural spectral cues that vary systematically with the location of the sound source. In the preferred embodiment, the

normal acoustic filtering of the outer ear is preserved by using a completely-in-the-canal hearing-aid. In addition, in the preferred embodiment, binaural listening conditions should be provided to the hearing-aid listener. Either the listener has: (1) a good unaided ear and an aided ear or (2) two aided ears.

An advantage of this invention is that the high-frequency spectral cues that vary most with directions in space (those above 8 kHz) are presented to the listener in an audible form.

An advantage of this invention is that because the auditory system has greater frequency resolution at the lower frequencies, the frequency compression and/or frequency shift to lower frequencies that is described in this invention will help compensate for the hearing impaired listener's decreased frequency selectivity.

An advantage of this invention is that because the auditory system is capable of relearning monaural spectral cues for sound spatialisation, the listener will be able to learn to use the altered spectral cues that result from the frequency compression and/or frequency shift to a lower frequency. Recent research has demonstrated that following a period of 20 to 30 days accommodation, the human nervous system is able to use new spectral localisation cues to support control levels of localisation accuracy (see Hofman, P.M., J.G.A.V. Riswick, and A.J.V. Opstal, *Relearning sound localization with new ears*. Nature Neuroscience, 1998. 1(5): p. 417 – 421). The length of time necessary to adapt to these new cues is comparable to the time normally required to accommodate to conventional hearing aids and also requires that the hearing impaired listener wear the hearing aid(s) consistently for relatively long periods at a time.

An advantage of this invention is that it restores some degree of spatial hearing to the hearing impaired listener. This spatial auditory perception provides a basis for speech segregation in noisy acoustic environments. Unlike the speech enhancement technologies in other hearing aid systems, the "spatial hearing aid" described in this invention supports the segregation of multiple talkers from each other as well as from other background noises by exploiting the binaural and spectral cues to the different locations of the sound sources. In addition, the restored spectral cues give rise to a clear percept of externalized sound sources, which in turn maximizes the potential for information unmasking. It has been known for some time that the relative locations of competing sounds affect their ability to mask or interfere with the understanding of speech (see Bronkhorst, A.W., *The cocktail party phenomon: A review of research on speech intelligibility in multiple-talker conditions*, Acustica, 2000. 86: p. 117-128). When a talker and a masker (another talker or noise) are co-located, there is a reduction in the intelligibility of the talker. When the masker is moved away from the target talker there is a release from masking of up to 15dB. This has principally been attributed to (i) energetic unmasking where there is an improvement in the signal-to-noise ratio at one ear and (ii) the difference in the binaural differences of each sounds at both ears. Recent research has also demonstrated that the perception of the different locations also plays a key role in providing some unmasking: This additional increase in intelligibility has been attributed to the listener being better able to attend to and "stream out" the target talker from the

masking talker and is referred to as informational unmasking (Freyman, R.L., *et al., The role of perceived spatial separation in the unmasking of speech*, Journal of the Acoustical Society of America, 1999. 106(6): p. 3578-358).

An advantage of this invention is that it provides the basis for locating the source of sound(s) and therefore aids in normal acoustic navigation.

An advantage of this invention is that is makes use of the high frequency information provided by the fricatives and plosives of speech to aid in the spatialisation of the speech.

An advantage of this invention is that it provides a means to optimise the utilisation of spatial information by the hearing-impaired listener by customising the high-frequency band to the listeners'optimal high-frequency hearing range.

It is anticipated that the invention will support spatial hearing in most listeners with mild to moderate hearing-impairment and who are able to wear a CIC hearing-aid.

It will be appreciated by persons skilled in the art that numerous variations and/or modifications may be made to the invention as shown in the specific embodiments without departing from the spirit or scope of the invention as broadly described. The present embodiments are, therefore, to be considered in all respects as illustrative and not restrictive.

Dated this Eleventh day of August 2003

Secretary for Vast Audio Pty Ltd

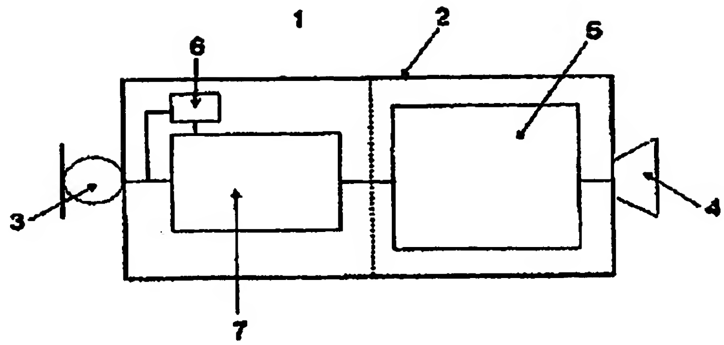

Figure 1.